D.3.1.1. Training material - geothermal resource management

February 2017

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Geothermal resource management

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Contents

Interreg
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Part I – Overview of geological, hydrogeological and geothermal conditions of the DARLINGe countries

- Hungary
- Slovenia
- Croatia
- Serbia
- Bosnia and Herzegovina
- Romania

Part II – Introduction to deep geothermal energy: play types, potential estimation methods, geothermal modelling, classification of resources/reserves

- Basic concepts of deep geothermal energy
- Geothermal Play Types
- Geothermal potential and estimation methods
- Geothermal processes – a numerical approach for reservoir evaluation
- Classification of geothermal resources / reserves
- Methods to outline and characterize potential geothermal reservoirs at regional scales (Experiences from TRANSENERGY project)

Contents

Part III – Utilization and management of hydrothermal resources

- Geothermal contexts of River Basin Management Plans and other (transboundary) groundwater management initiatives
- The benchmark system of the TRANSENERGY project - ways forward in DARLINGe
- Some practical aspects and good practices of thermal water direct uses

Part IV – Geo-techno-economic and environmental aspects of geothermal direct use projects

- Geological risk mitigation
- Experience from geothermal and hydrocarbon concessional works in Hungary
- THE UNFC-2009 classification scheme as a possible tool for complex project characterisation and ranking
- Economic considerations of geothermal projects
- Environmental aspects and social acceptance

Part V – Data integration and visualization

- Overview of existing web-based geothermal information systems

Part I – Overview of geological, hydrogeological and geothermal conditions of the DARLINGe countries

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Hungary

Geological setting, geothermal conditions

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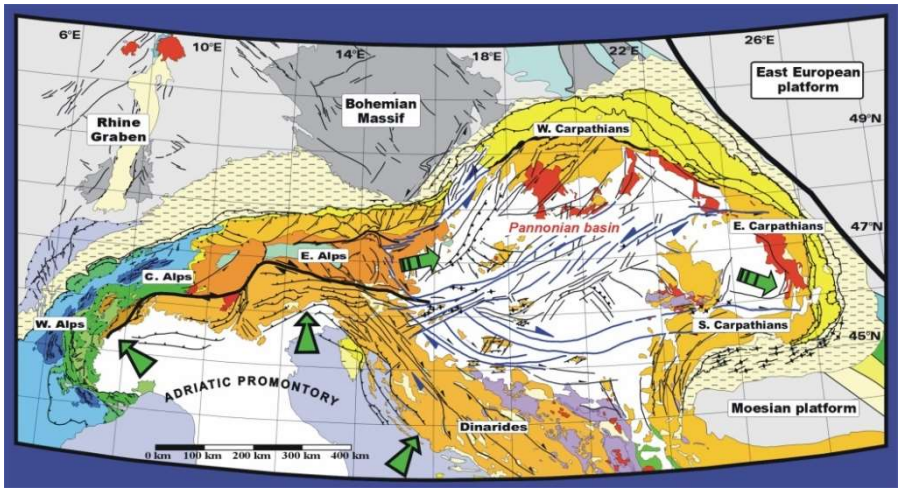
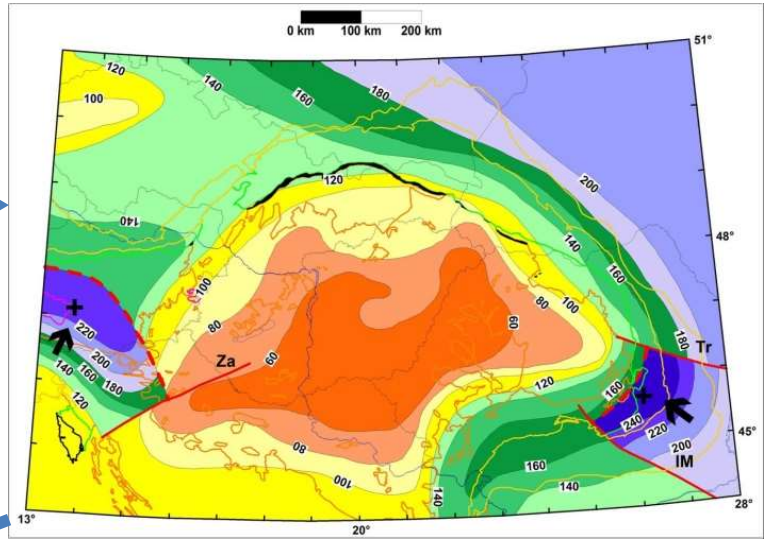
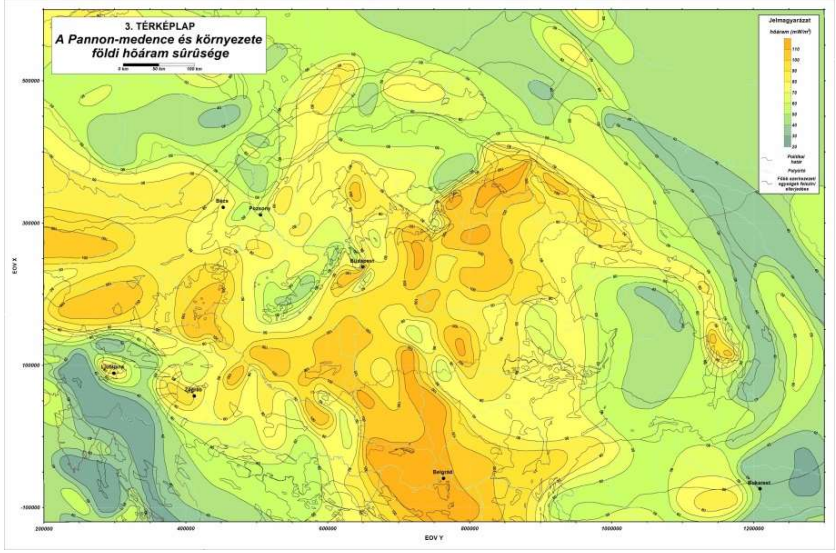




Basin formation: Early-Middle Miocene crustal extension

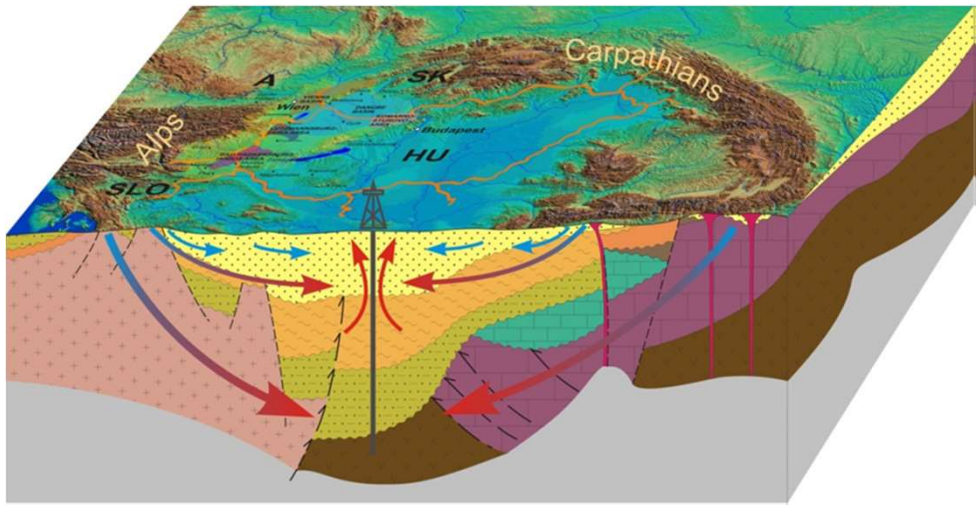
Streched (thinned lithosphere)



High heat flux (90-100 mW/m^2) – continental average (60 mW/m^2).

Geothermal gradient 45 °C/km (World average: 20-25 °C/km)

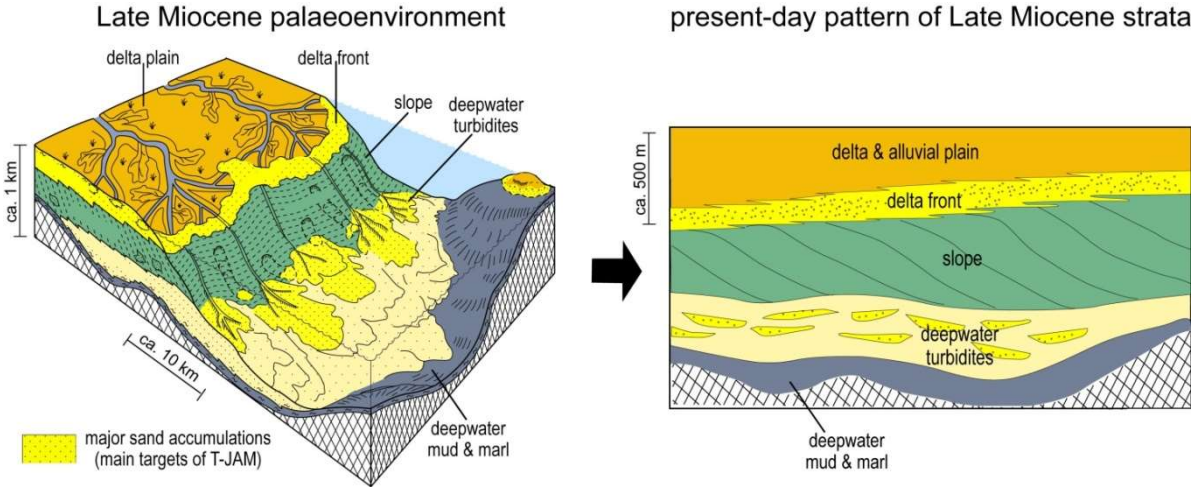
Geological setting, geothermal conditions



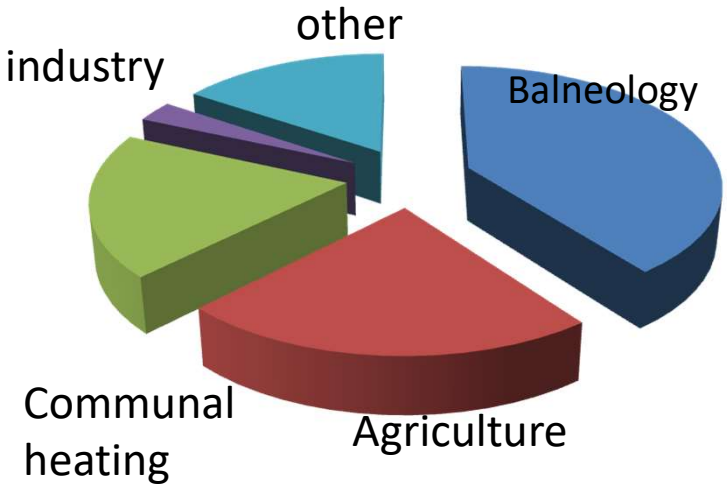
2 major geothermal reservoirs

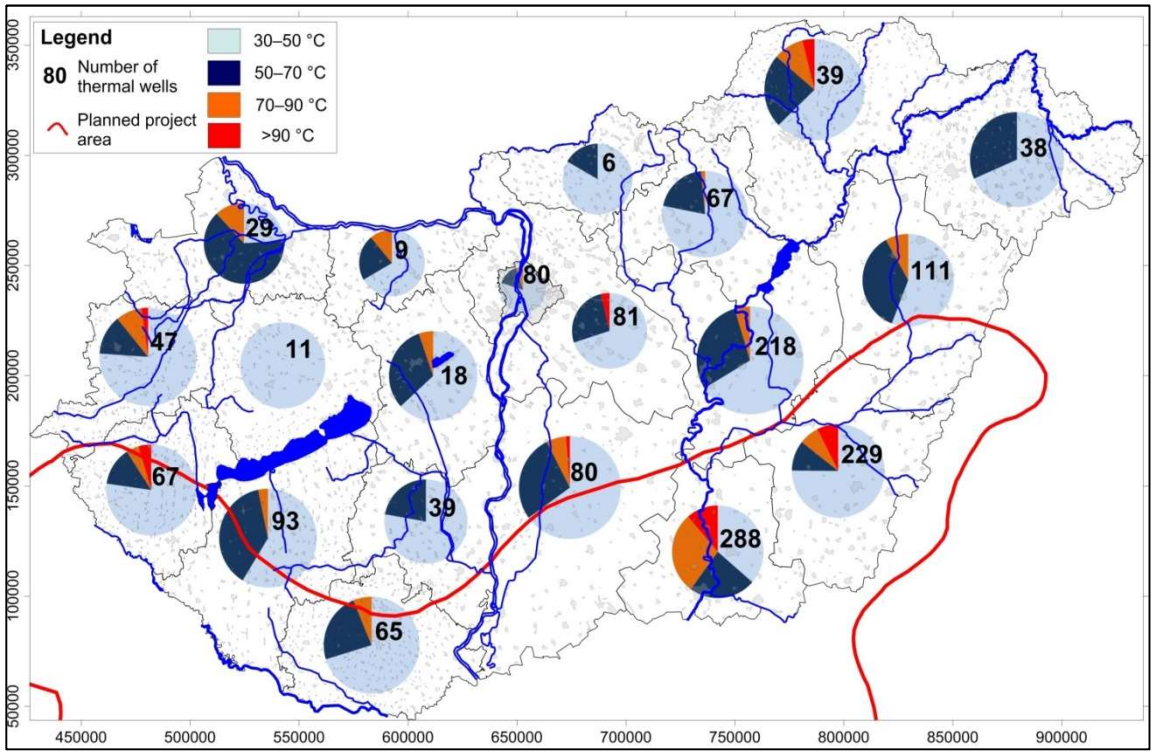
- Karstified fractured-weathered zones (Palaeozoic-Mesozoic basement carbonates):

- Multilayered porous sediments (Upper Miocene-Pliocene "Pannonian" basin fill sequence) : intergranular / porous reservoirs: best: delta (shelf) front sands



Current utilization





Red line: provisional contour of the DARLINGe area

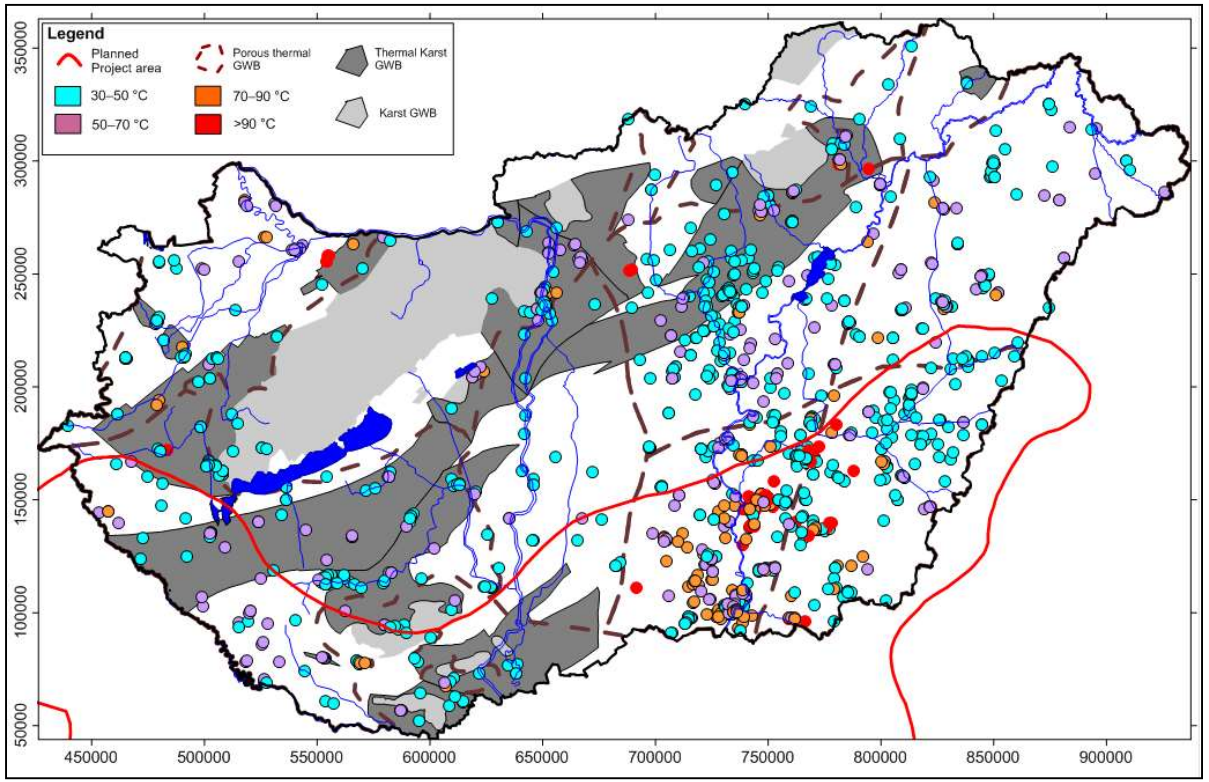
Current utilization

Agriculture: major sector for direct heat utilization (greenhouses, plastic tents)

Industrial purposes: few wells, typical outflow temperature is 40-50 °C

Balneological: ~255 wells, 40-50 °C outflow temperature

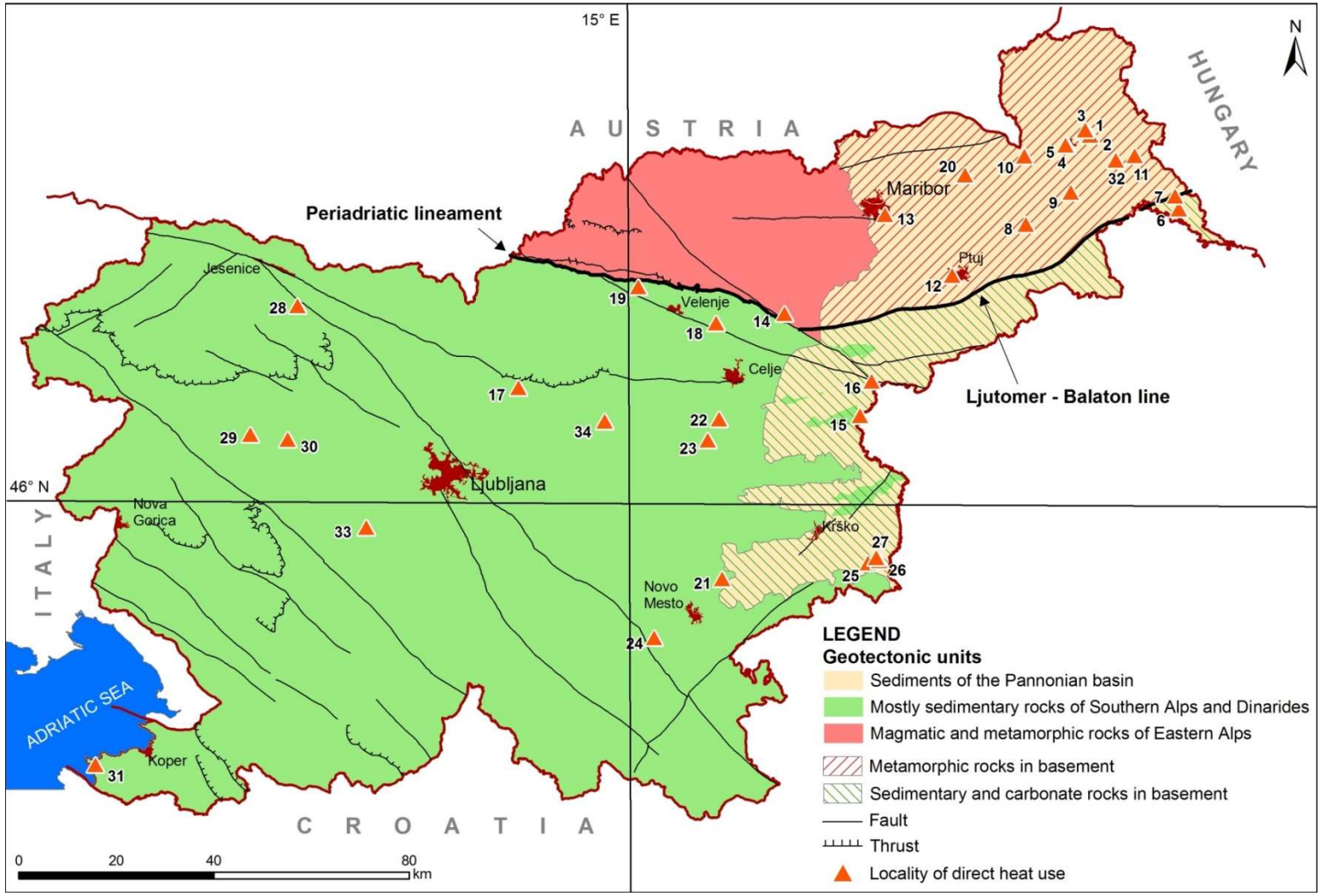
District heating: 21 towns in 2016 (thermal water heating cascade system



Red line: provisional contour of the DARLINGe area

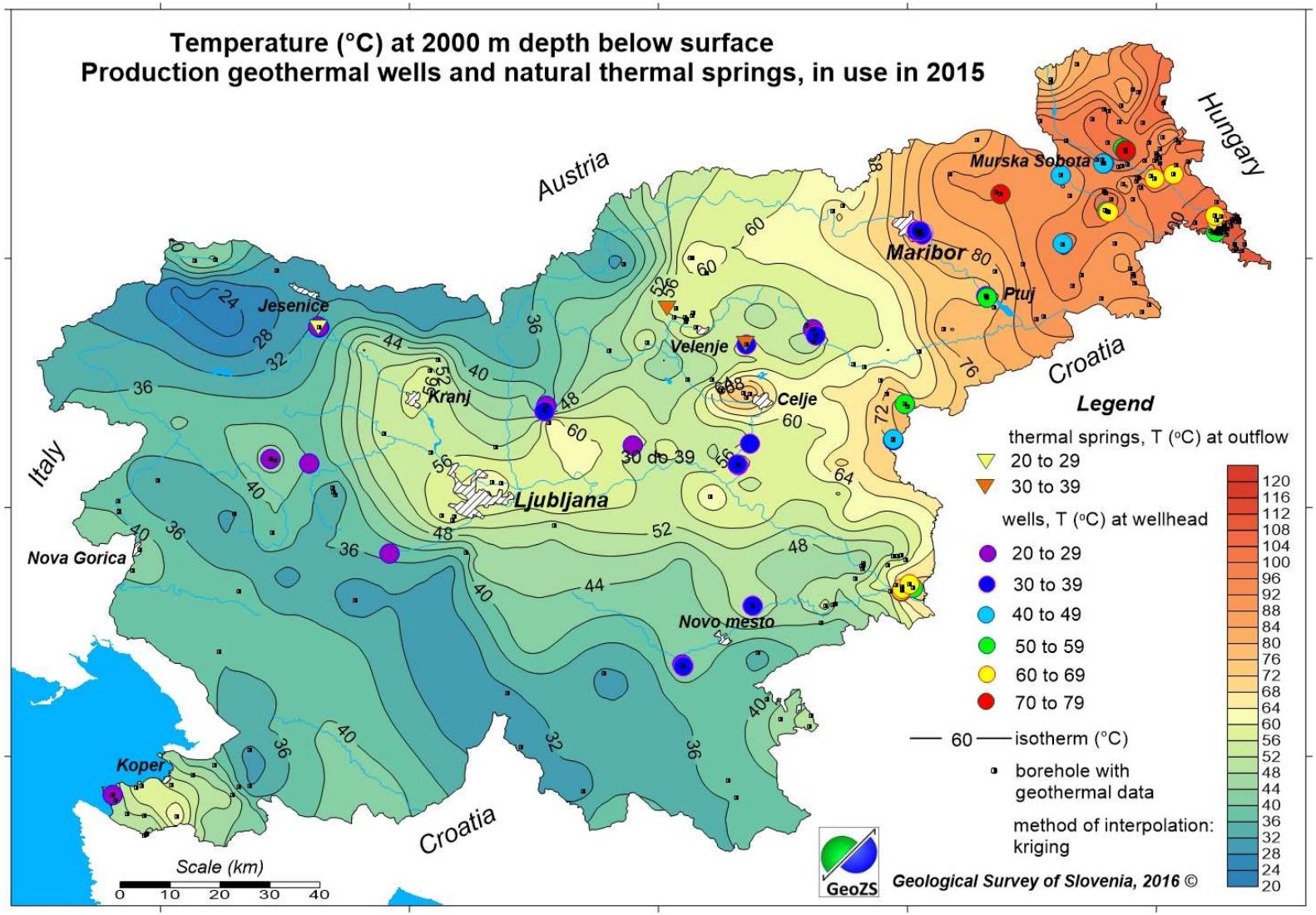
Slovenia

Geological setting



(Rajver et al., 2016).

Geothermal conditions



Geothermal conditions

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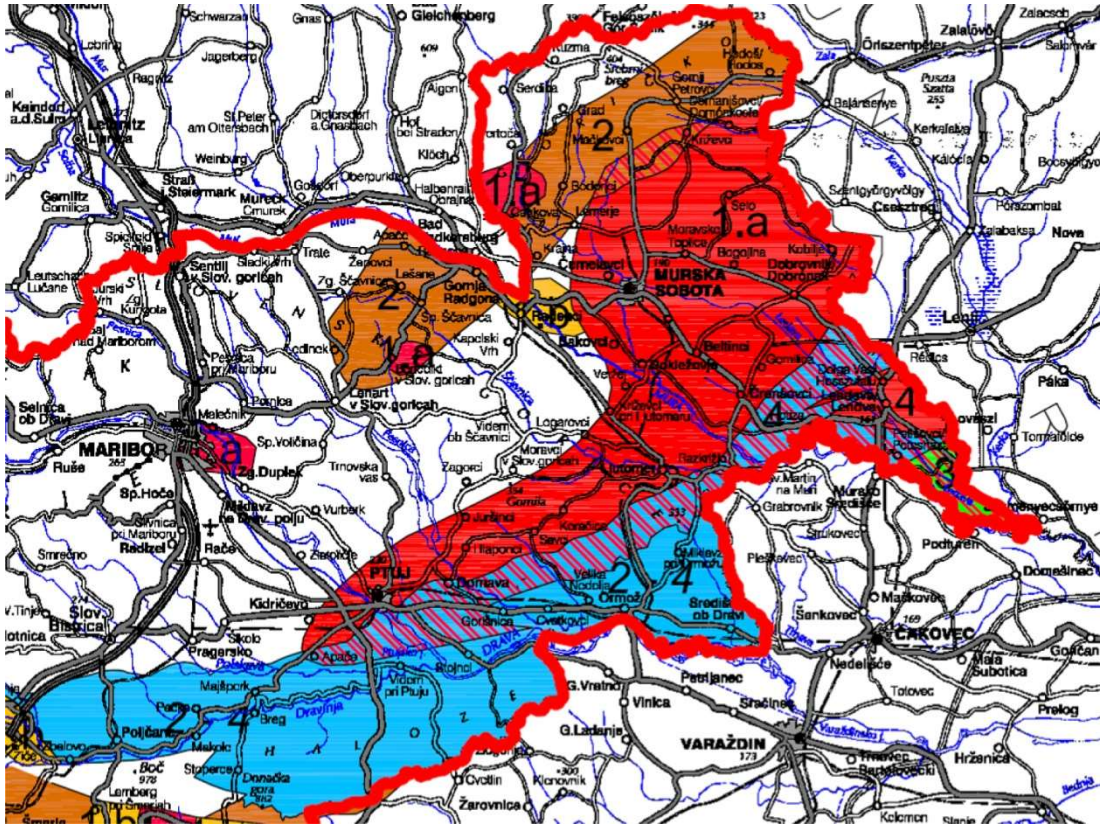

Useful (Economic) resources:		
Identified		**Undiscovered**
1.a	proven	2
1.b	probable	
1.c	possible	
Subeconomic resources:		
3	Identified	
4	Undiscovered	
4	Proven useful identified resources (1.a) lying over undiscovered and/or subeconomic resources	

Geothermal resources of NE-Slovenia

(Rajver et al., 2016).

Current utilization

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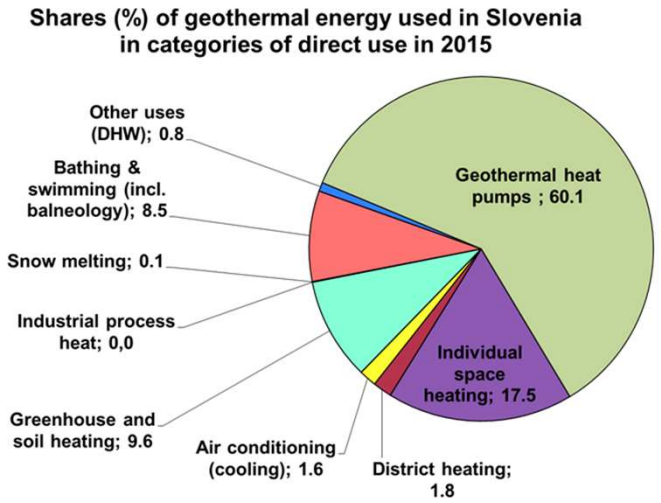
Direct use from thermal water at 34 localities; Installed capacity: 65.62 MW_t, Annual thermal energy used in 2015: 486 TJ (=11.61 ktoe)

ca 9350 geothermal (ground-source) heat pump units (GSHP), both water-source (W) and closed-loop ground-coupled (H and V) systems; their total capacity: 136.64 MW_t Annual thermal energy used in 2015: 732.09 TJ (=17.49 ktoe) of thermal energy.

Total: from capacity of 202.25 MW_t the annual geothermal energy used in 2015: 1218.09 TJ/yr (=29.094 ktoe=338.36 GWh), equals 0.43% of gross domestic energy use at level of primary energy supply (282.2 PJ in 2014).



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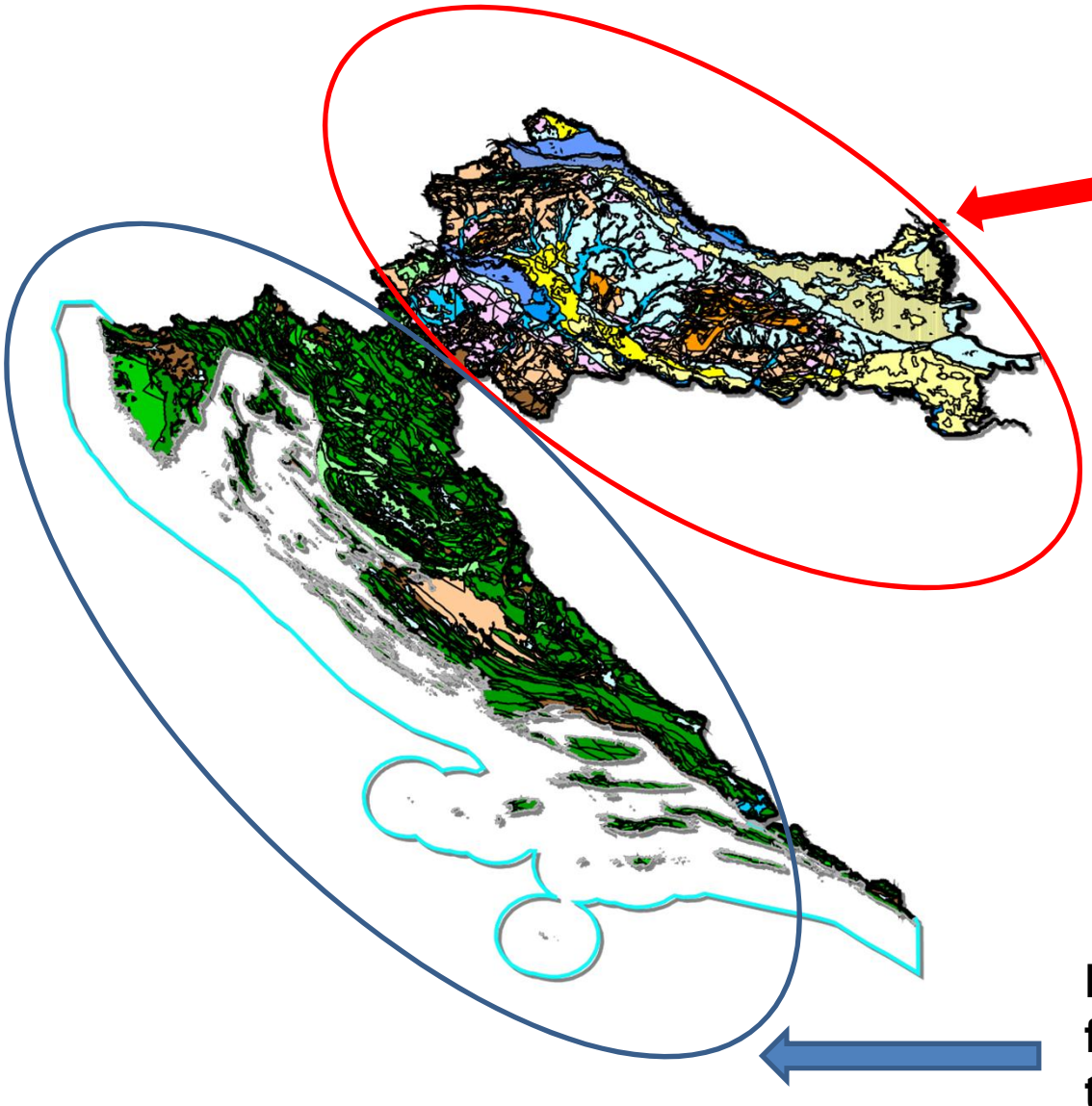
Croatia

Geological setting

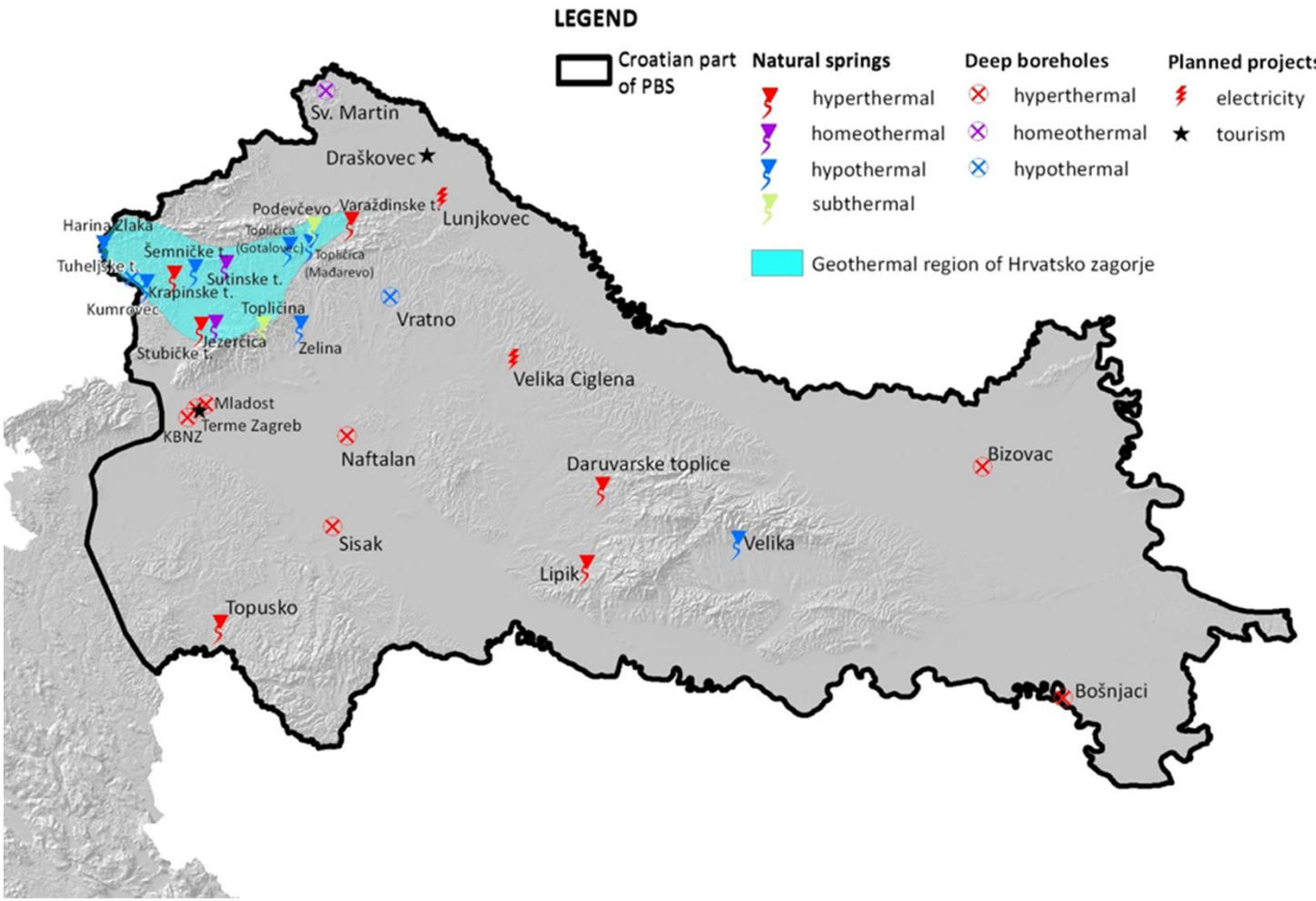


Pannonian part –

- **sedimentary basin conditions (Mura, Drava, Sava and Slavonija-Srijem depressions)**
- **favorable geothermal conditions -average heat flow is 76 mW/m2, and geothermal gradient 0,049 °C/m**
- **sandstones, dolomites, metamorphites**
- **T 50 – 200 °C**

Dinaric region - low heat fow 29 mW/m2 and temperature gradient 0,018 °C/m

Geothermal conditions



Current utilization

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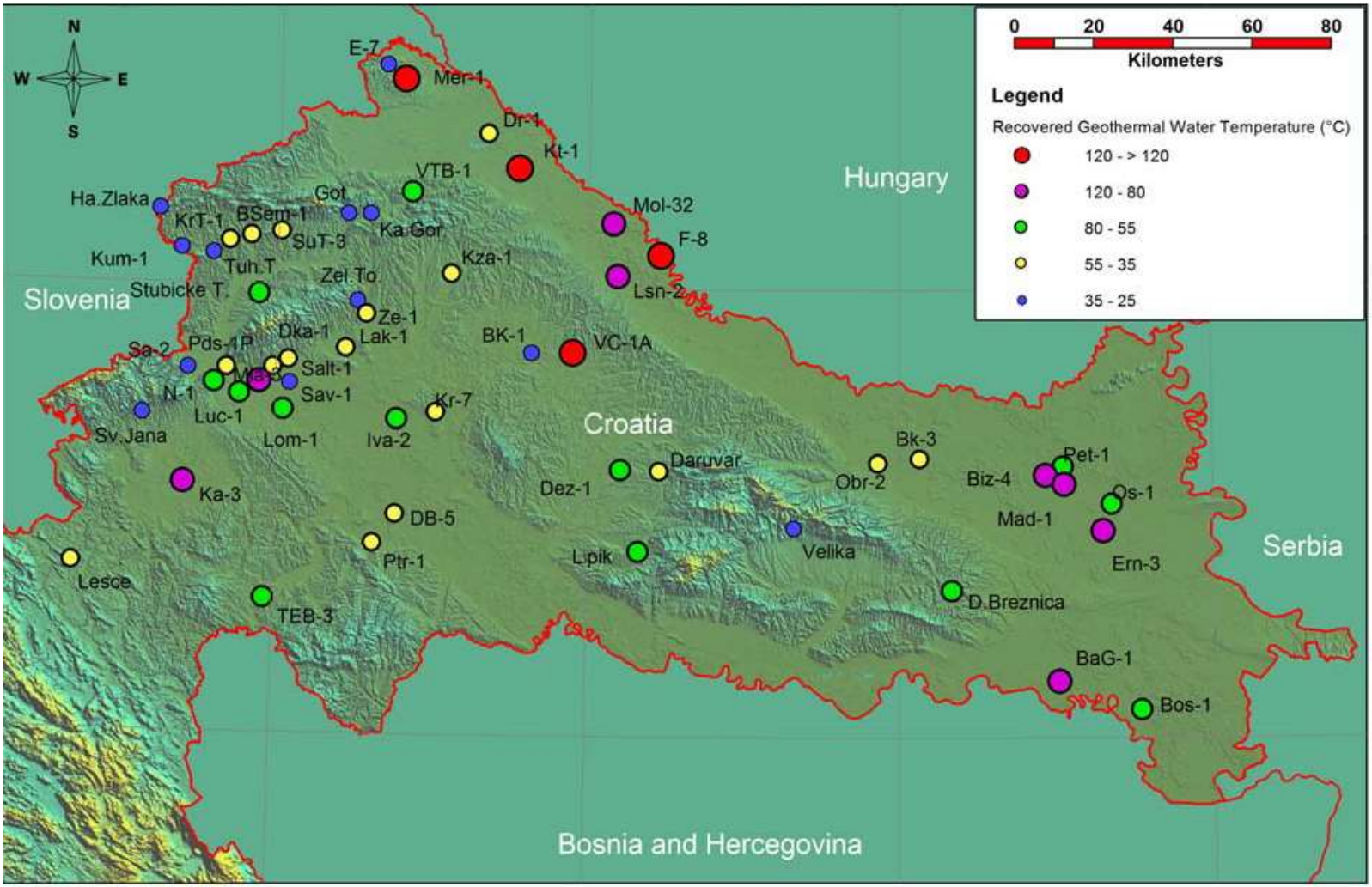
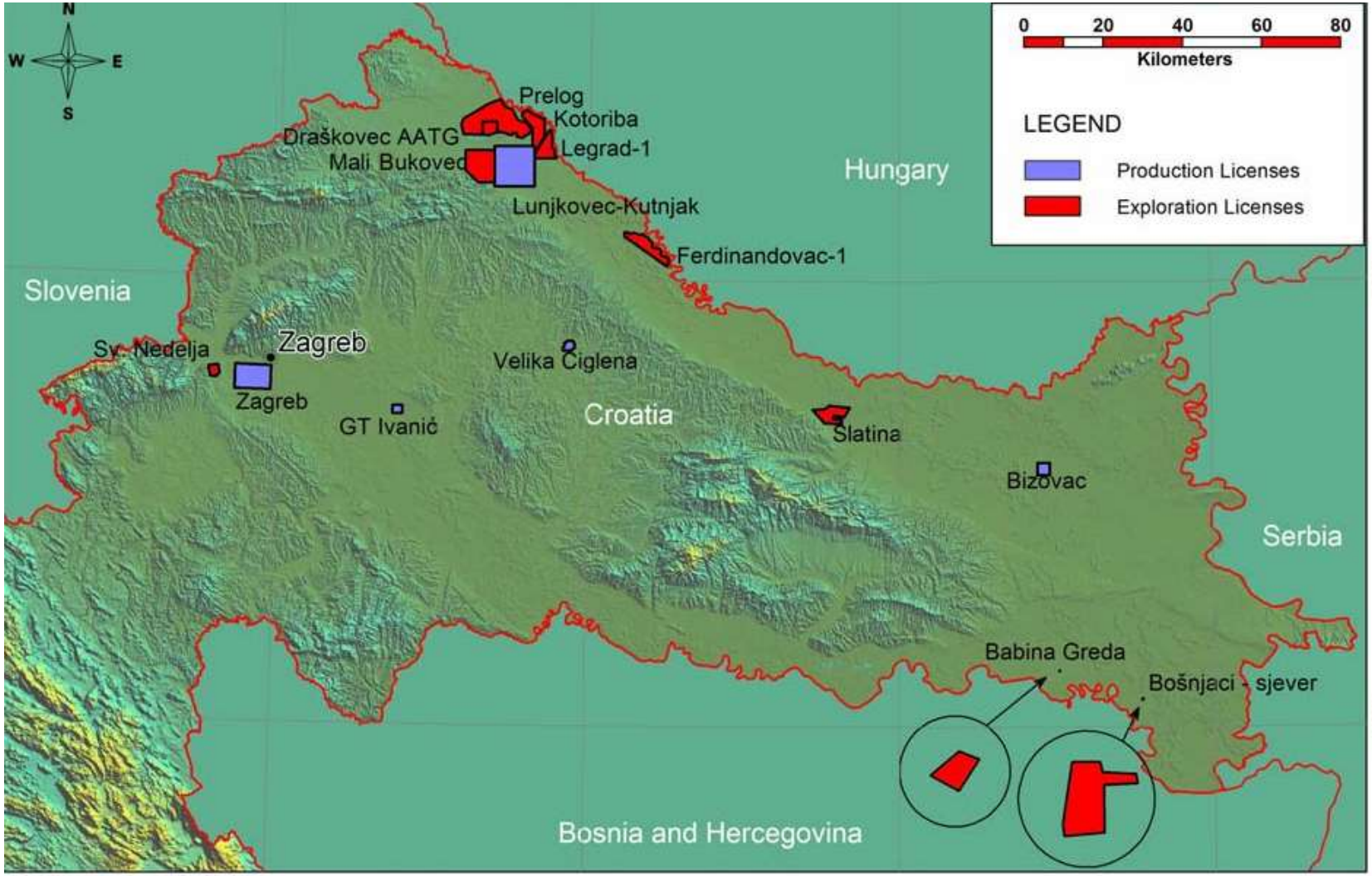


Known geothermal water sources in Croatia

Current utilization



Exploration and production blocks licensed by the government in the northern Croatia

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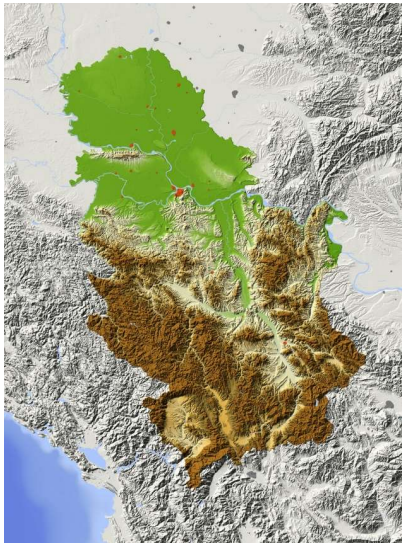
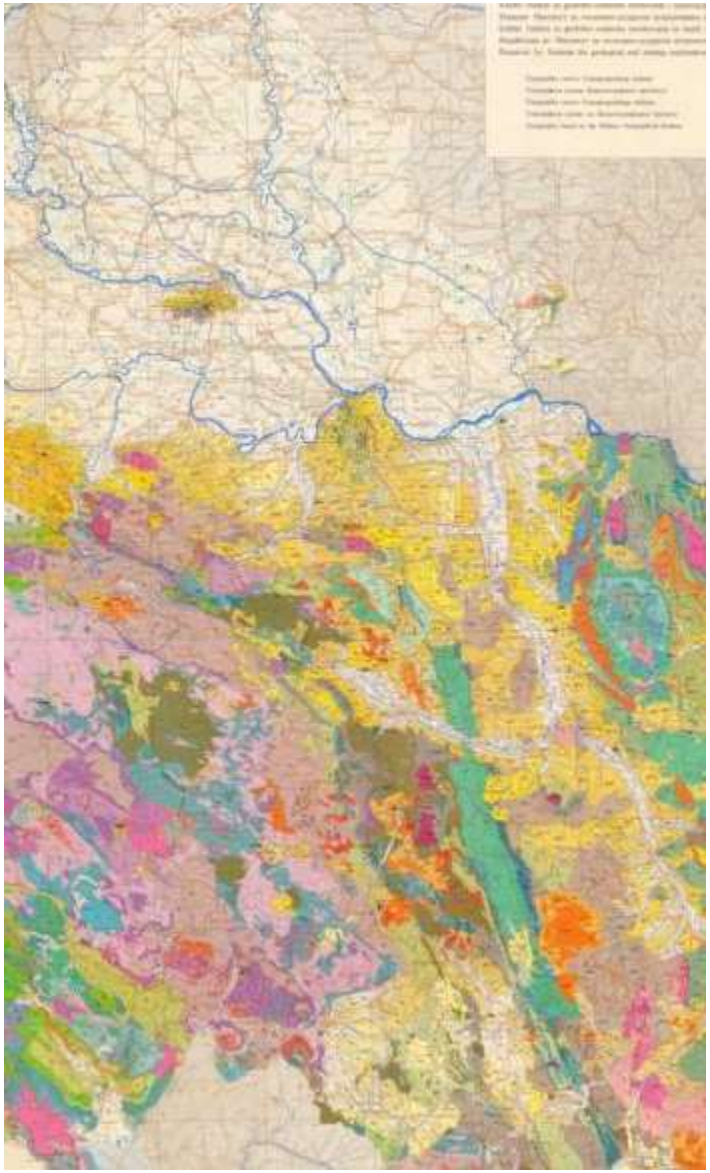
Serbia

Geological setting





Geothermal conditions

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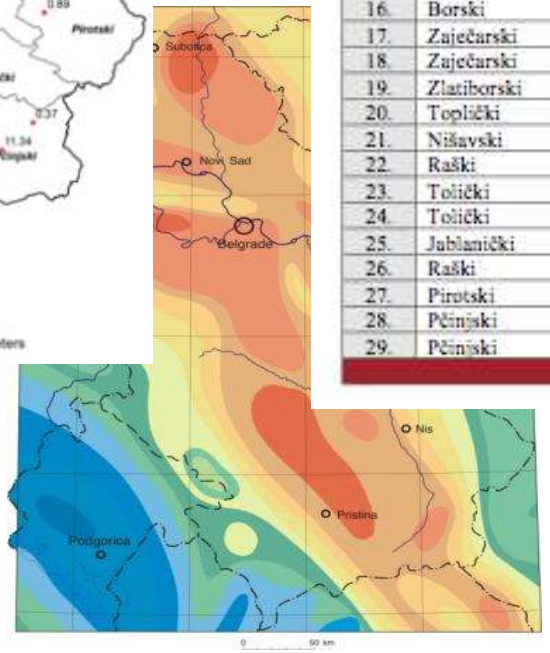

Br.	Okrug	Lokalitet	Tip	T	Q	Termalna snaga
		Banja		°C	l/s	MWt
1.	Severno-banatski	Kanjiža	bunar	27-63	19	2.38
2.	Zapadno-bački	Junaković	bunar	46-49	20	2.26
3.	Severno-banatski	Bečej	bunar	65	25	4.71
4.	Sremski	Vrdnik	bunar	33	45	2.45
5.	Beograd	Selters	bunar	32-60	20	2.09
6.	Podunavski	Palanački kiseljak	bunar	50	4	0.50
7.	Kolubarski	Ljig	bunar	33	4	0.22
8.	Mačvanski	Koviljača	bunar	30	20	0.84
9.	Šumadijski	Bukovička	bunar	31-34	3	0.18
10.	Moravički	Gornja Trepča	izvor i bunar	27-31	21	0.97
11.	Moravički	Ovčar	izvor i bunar	36-38	50	3.77
12.	Pčinjski	Vrnjačka	izvor i bunar	36	6	0.40
13.	Raški	Mataruška	bunar	25-51	72	6.02
14.	Raški	Bogutovac	bunar	25	10	0.21
15.	Rasinski	Ribarska	izvor i bunar	44	37	3.72
16.	Borski	Brestovac	izvor i bunar	20-41	7	0.44
17.	Zaječarski	Gamzigrad	izvor i bunar	30-42	10	0.63
18.	Zaječarski	Soko	izvor i bunar	22-46	25	2.09
19.	Zlatiborski	Priboj	izvor	36	70	4.69
20.	Toplički	Lukovska	bunar	64-67	12	2.31
21.	Nišavski	Niška	izvor	37	35	2.49
22.	Raški	Jošanička	izvor	50-77	19	3.58
23.	Tolički	Kuršumlijska	bunar	64	16	2.95
24.	Tolički	Prolom	bunar	31	10	0.46
25.	Jablanički	Sijarinska	izvor i bunar	61-76	36	7.53
26.	Raški	Novopazarska	izvor	51	5	0.65
27.	Pirotski	Zvonačka	izvor	28	5	0.17
28.	Pčinjski	Vranjska	izvor i bunar	63-95	80	19.08
29.	Pčinjski	Bujanovac	bunar	42	7	0.64
		UKUPNO			693	78.40

Geothermal conditions of the Pannonian basin part

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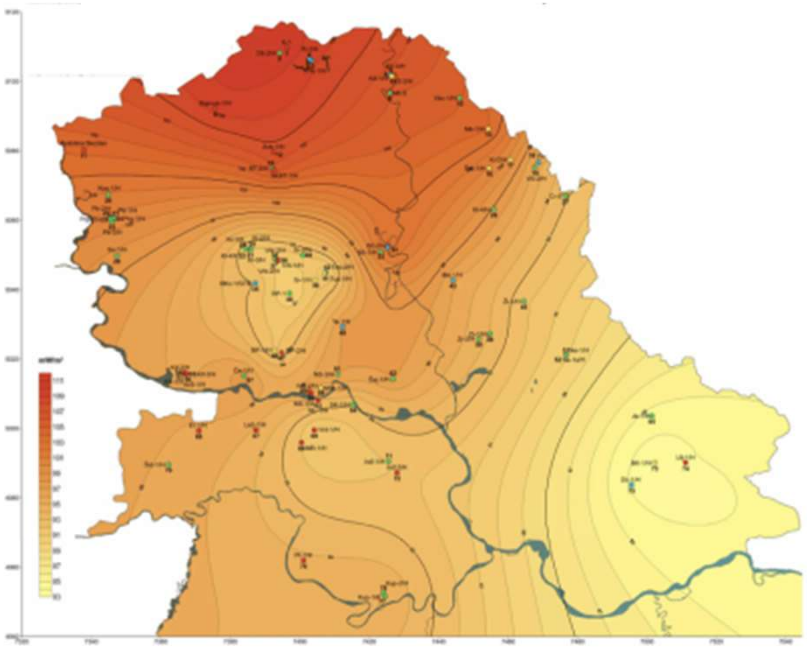
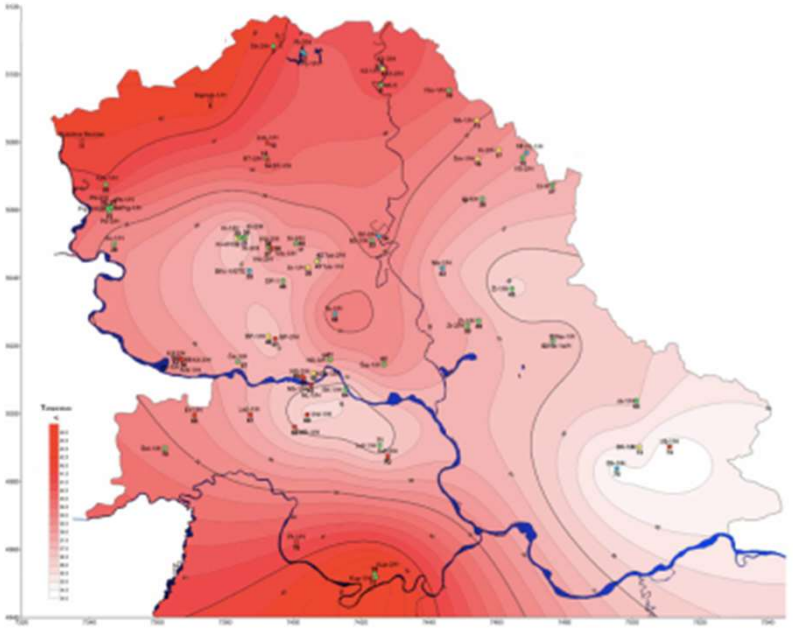
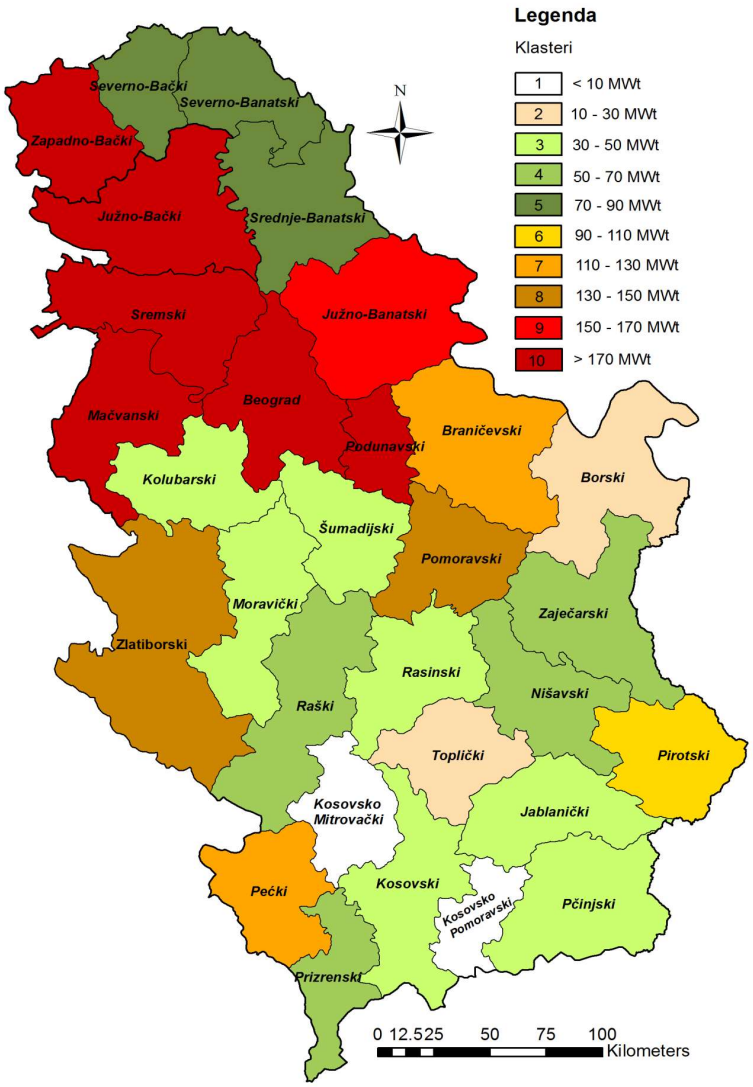
MAP OF HEAT FLOW DENSITY



MAP OF TEMPERATURE AT THE DEPTH OF 500 m

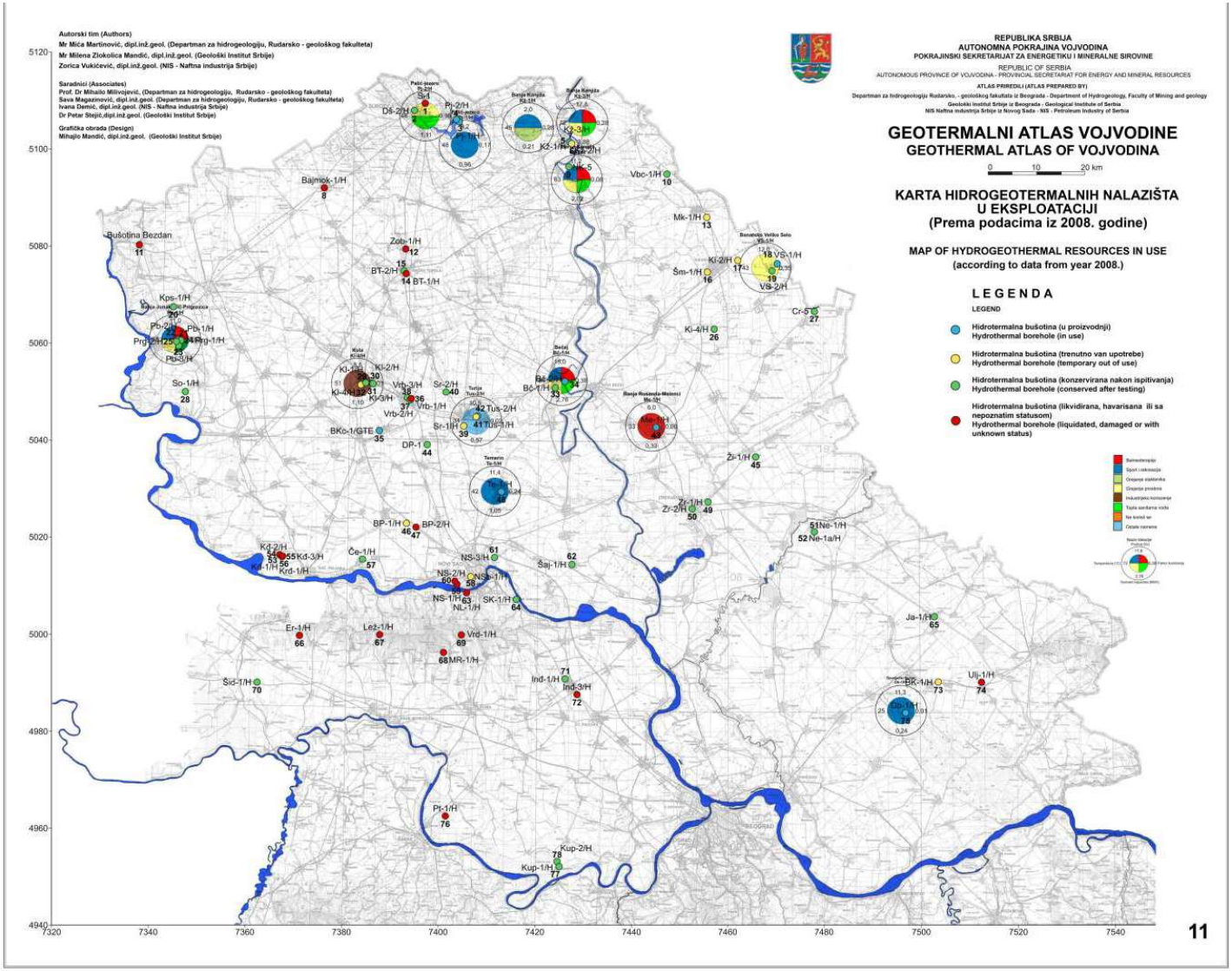


Geothermal potential



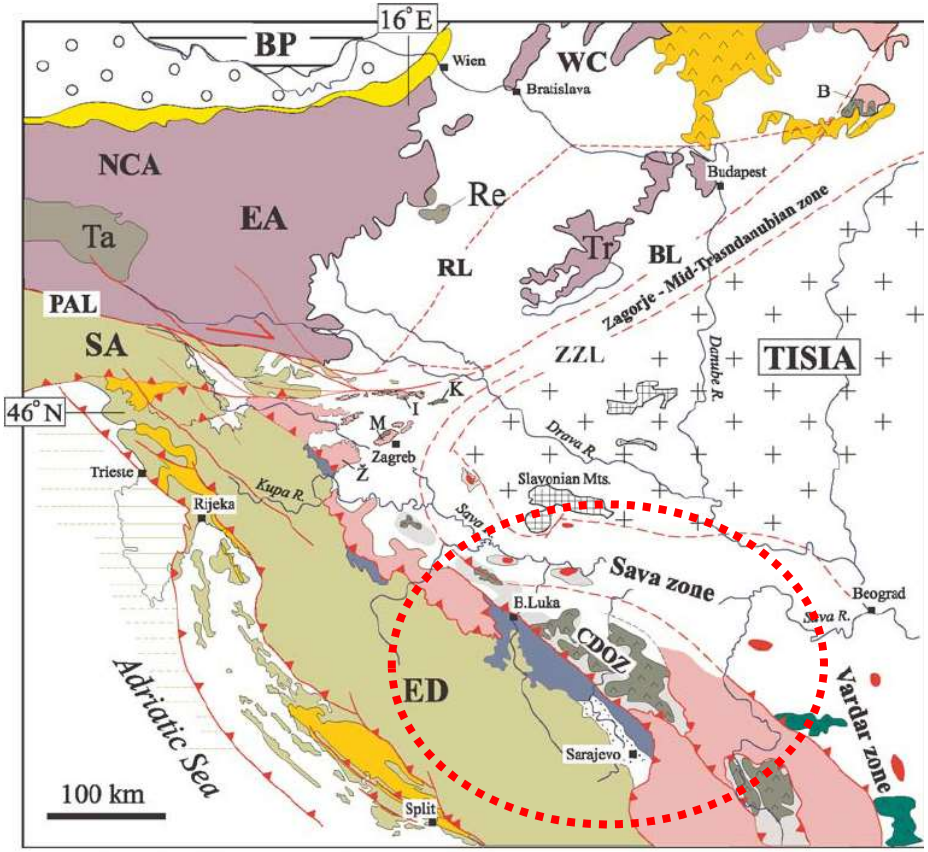
Region	Districts	Potential thermal power	Effective thermal power	Total thermal power
		1	2	3=1+2
		MW_t	MW_t	MW_t
Beograd	Urban city area	1.200		1.200
	City area	1.100		1.100
Vojvodina	Severno bački	37.4	45.9	83.3
	Zapadno bački	28.5	157.1	185.6
	Južno bački	65.6	139.0	204.6
	Severno banatski	36.3	46.2	82.5
	Srednje banatski	29.9	57.3	87.2
	Južno banatski	41.8	126.4	168.2
	Sremski	37.3	250.6	287.9
Šumadija i Zapadna Srbija	Mačvanski	37.1	233.7	270.8
	Kolubarski	9.2	32.8	42.0
	Zlatiborski	15.7	120.9	136.6
	Moravički	11.2	21.7	32.9
	Šumadijski	12.2	28.9	41.1
	Rasinski	11.1	20.7	31.8
	Raški	10.5	57.4	67.9
	Pomoravski	29.7	106.7	136.4
Južna i Istočna Srbija	Podunavski	21.5	160.1	181.6
	Braničevski	20.1	98.0	118.1
	Borski	7.2	18.7	25.9
	Zaječarski	28.0	32.6	60.6
	Nišavski	24.4	45.3	69.7
	Pirotski	27.2	76.3	103.5
	Toplički	3.7	10.1	13.8
	Jablanički	17.8	28.6	46.4
	Pčinjski	14.7	22.9	37.6
Kosovo	Kosovsko-Mitrovački	3.6	4.2	7.8
	Kosovski	8.9	26.0	34.9
	Pećki	28.2	92.7	120.9
	Kosovsko-pomoravski	1.8	1.8	3.6
	Prizrenski	10.5	43.4	53.9
TOTAL		**631.1**	**4.414**	**5.045**

Current utilization



Bosnia and Herzegovina

Geological setting



EXTERNAL DINARIDES (ED) & SOUTHERN ALPS (SA)

- Imbricated Adriatic plate margin units largely composed of Palaeozoic basement and Mesozoic carbonate platform rocks
- External Dinarides flysch belt
- Undeformed Adriatic foreland

EASTERN ALPS (EA) & WESTERN CARPATHIANS

- Austroalpine units: Northern Calcareous Alps (NCA) West Carpathians (WC) and Transdanubian Range (Tr)
- Penninic units: Tauern window (Ta) & Rechnitz (Re)
- Penninic Alpine–Carpathian flysch belt & Helvetic units
- Alpine–Carpathian foredeep
- Neogene volcanic rocks

INTERNAL DINARIDES

- Bosnian flysch zone
- Adriatic plate margin units involved in Late Jurassic ophiolite obduction

Central Dinaridic ophiolite zone (CDOZ)

- (a) Ophiolite massifs (b) Jurassic ophiolitic mélange

K, I, M, Ž - Kalnik, Ivanščica, Medvednica and Žumberak Mts.

Sava-Vardar zone

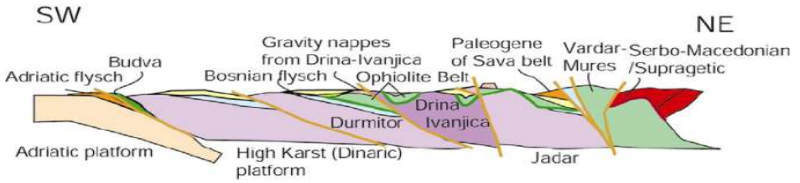
- (a) Cretaceous–Tertiary granodiorite intrusions and (b) Ophiolite massifs
- Neogene–Quaternary fill of the Pannonian basin

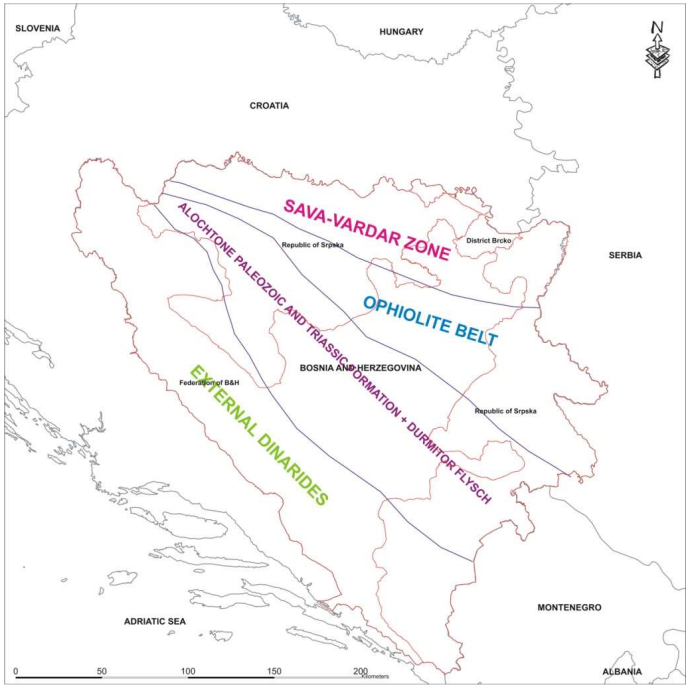
TISIA

- Tisia units, (a) covered by Neogene–Quaternary deposits & (b) exposed on the surface

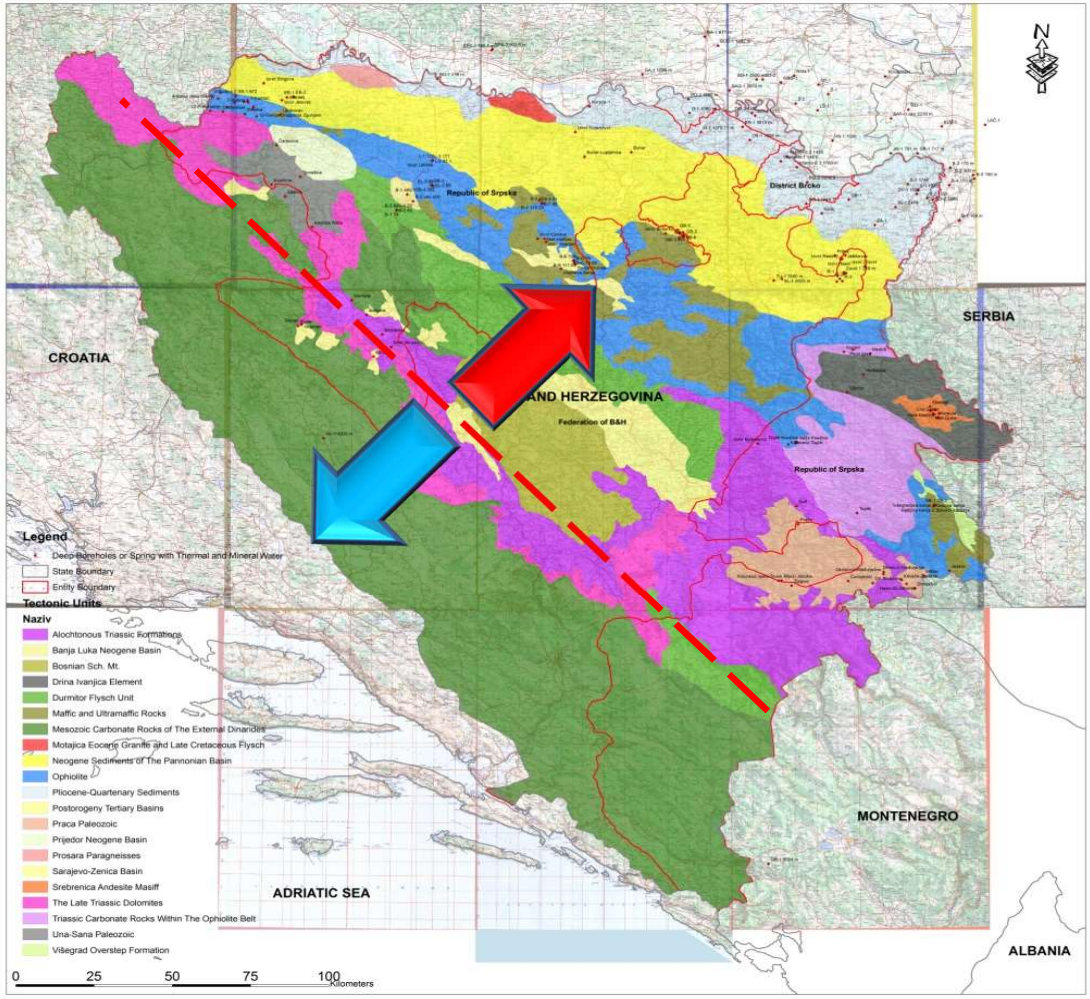
EUROPEAN FORELAND

- Bohemian Promontory (BP)

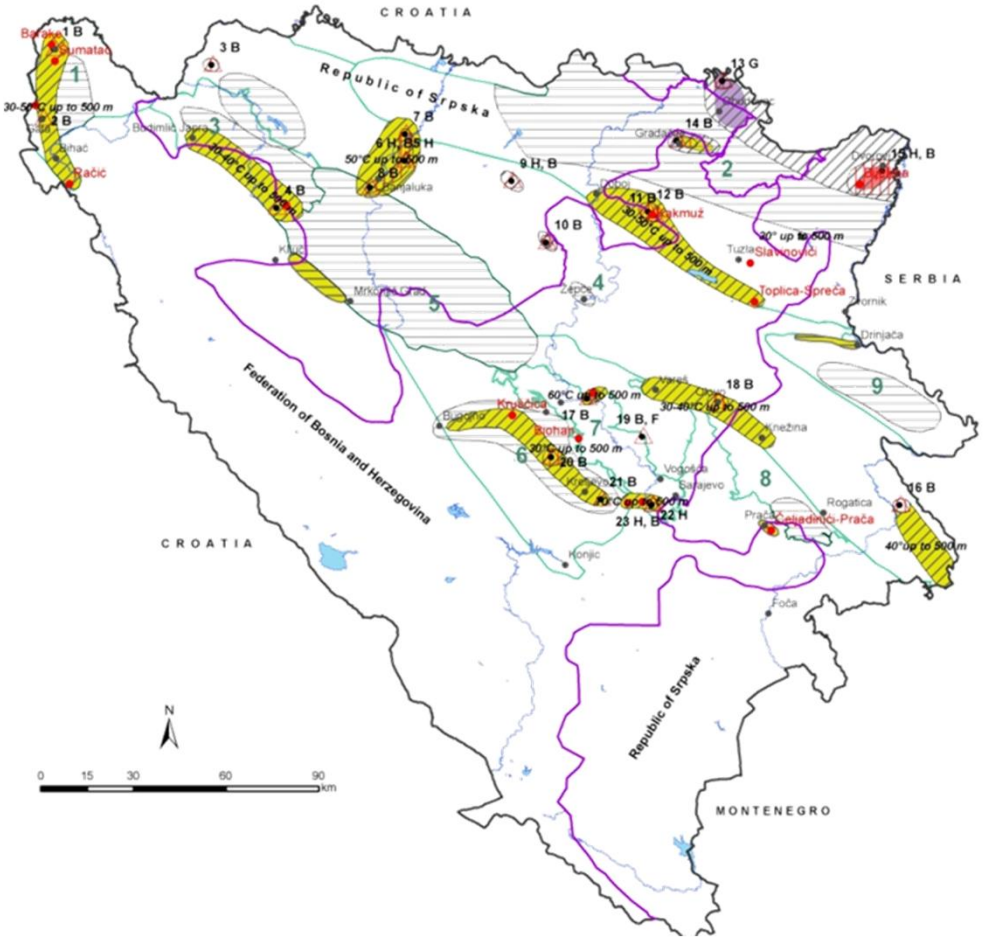




Geothermal conditions



Geothermal conditions



Utilization of geothermal energy for direct heat

F = Fish farming
H = Individual space heating (other than heat pumps)
B = Bathing and swimming (including balneology)
G = Greenhouse and soil heating

Hydrogeothermal regions

- Border of hydrogeothermal regions
- 1 Mesozoic massif of NW Bosnia
- 2 Mesozoic and Tertiary artesian basins of northern Bosnia
- 3 Una-Sana Paleozoic massif
- 4 Ophiolite massif
- 5 Mesozoic Mid-Bosnian massif
- 6 Mid-Bosnian Paleozoic massif
- 7 Mid-Bosnian Mesozoic basin
- 8 Paleozoic massif of SE Bosnia
- 9 Paleozoic and Neogene massif of E Bosnia

Temperature and depth of aquifers

- 120-140°C at 2500 m
- 90-100°C at 2500 m
- 30-70°C up to 500 m

Proved and perspective geothermal zones

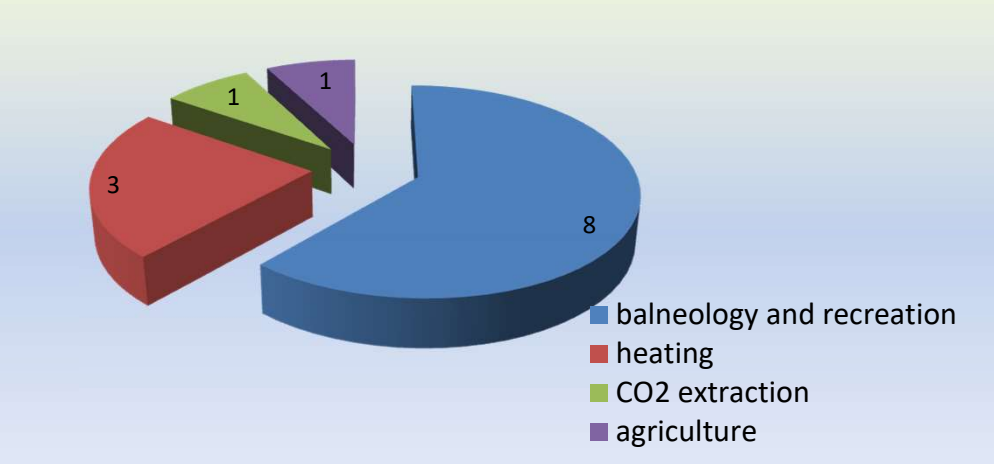
- Important proved resources in use
- Less promising geothermal zones
- Promising geothermal zones

Other symbology

- 1 Locality for direct heat utilization
- Other significant geothermal waters
- Important towns
- Boundary between Federation of B&H and Republic of Srpska

Current utilization

Locality	Borehole	Utilisation
Lješljani	BL-1	Recreation
Šeher	GŠ-1	Recreation
	B-1	
Slatina	KB-1	Balneology, heating
	SB-1	
	SL-1	
	SB-4	
Laktaši	L-1	Balneology
	L-3	
Kulaši	B-5	Balneology
Teslić	B-E	Balneology
Kakmuž, Petrovo	GB-6	CO_2 extraction
	TGP-2	
Dvorovi	S-1	Balneology, recreation, heating
Slobomir	GD-2	Heating, agriculture
Višegrad	SB-1	Balneology
	SB-2	

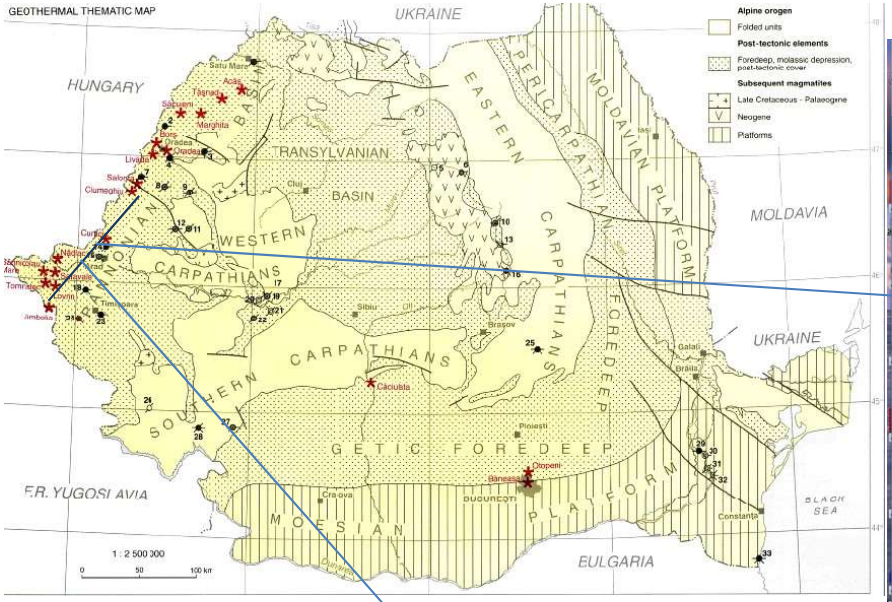


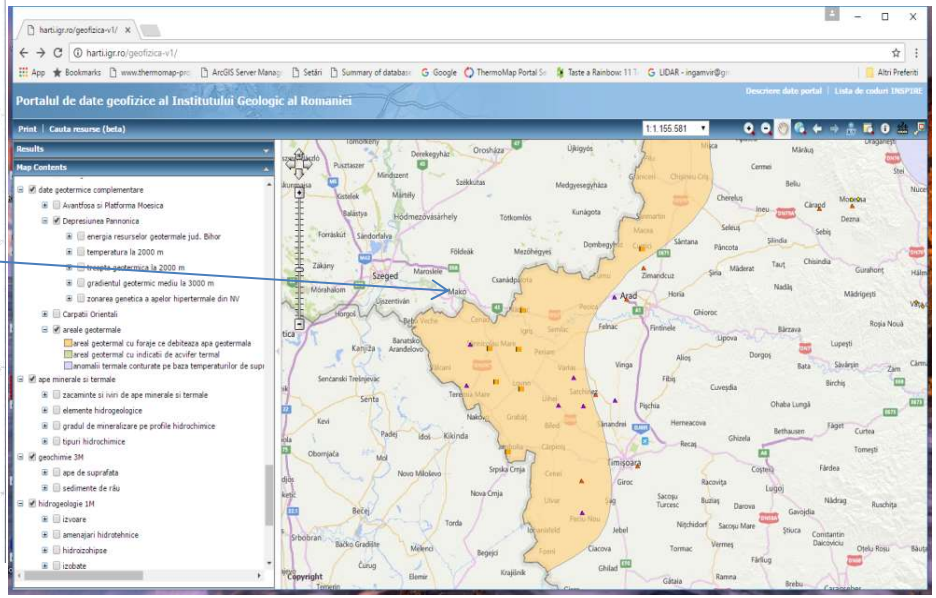
Balneology – traditionaly dominant, very rarely some other kind of use (heating, GE, agriculture)

Direct use of geothermal energy is implemented at 21 localities in B&H. Total used thermal energy from deep geothermal reservoirs is about 23 MW_{th} or 88.64 GW_{th}/yr and only 8,5MW_{th} is in Pannonian Basin.

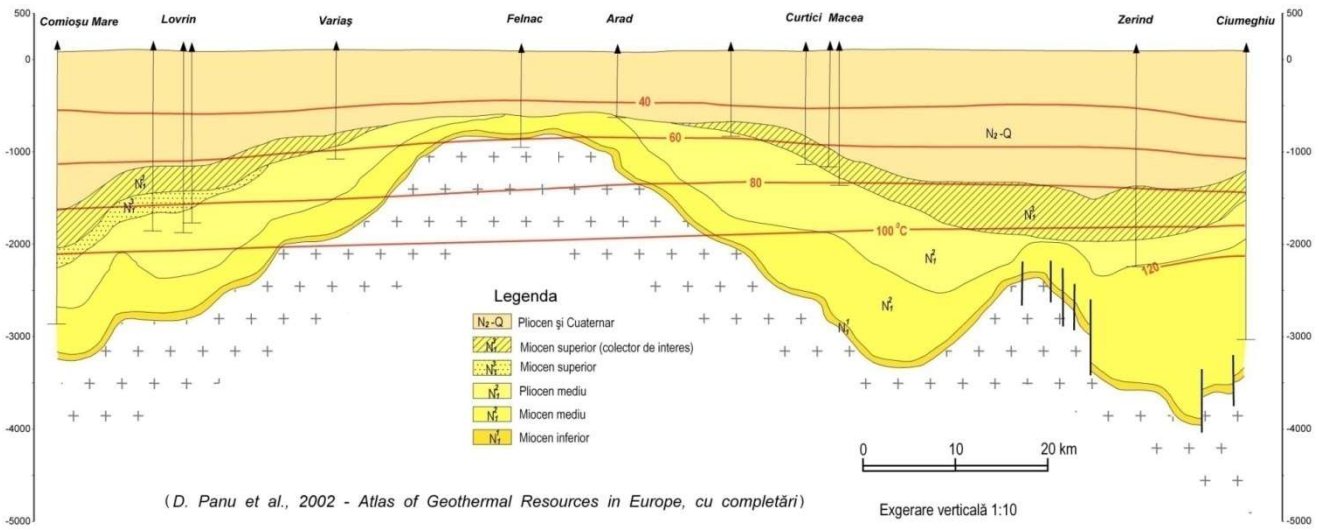
Romania

Geological setting

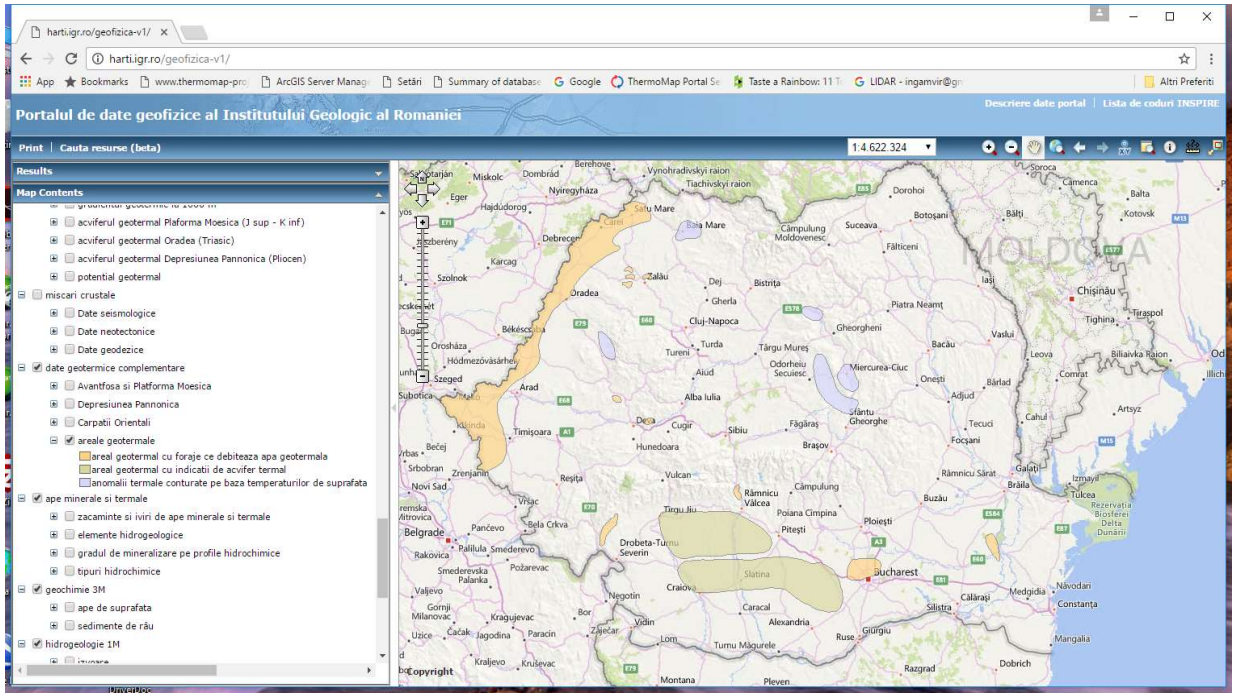




SV **Geological Profile of the Pannonian depression from Comlosu Mare to Ciumeghiu** NNE



Geothermal resources



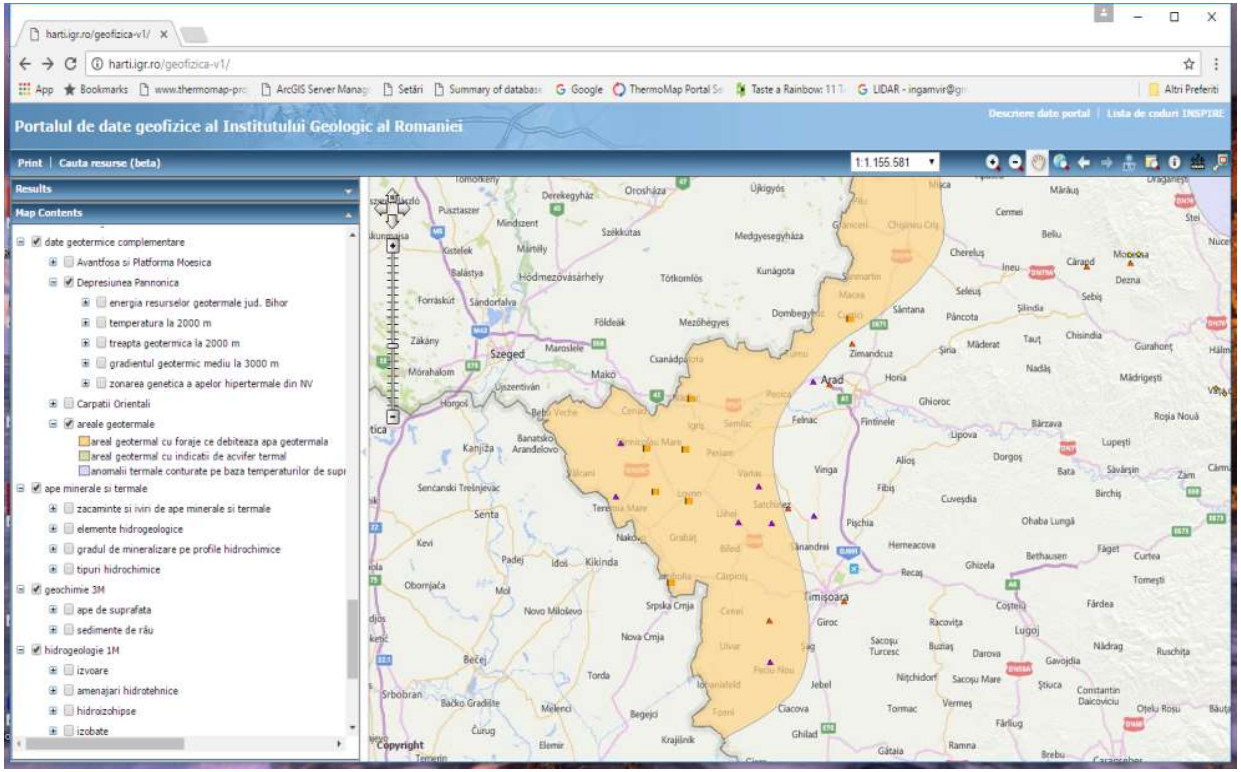
Location of the Romanian geothermal reservoirs

The geothermal systems discovered on the Romanian territory are located in porous permeable formations such as Pannonian sandstone, interbedded with clays and shales specific for the Western Plain, and Sennonian specific for the Olt Valley. Some geothermal systems are located in carbonate formations of Triassic age in the basement of the Pannonian Basin, and of Malm-Aptian age in the Moesian Platform

The first geothermal well in Romania was drilled in 1885 at Felix Spa, near Oradea. The well was 51 m deep, with a flow rate of 195 l/s and a temperature of 49°C. It was followed by the well drilled at Caciulata (in 1893 - 37°C), Oradea (in 1897 - 29°C) and Timisoara (in 1902 - 31°C).

The search for geothermal resources for energy purposes began in the early 60's, based on a detailed geological program for hydrocarbon resources (that had extensive budgets). There are over 200 wells drilled with depths between 800 and 3,500 m, that shows the presence of low enthalpy geothermal resources (40÷120°C), which enabled the identification of 9 geothermal areas, 7 in the Western part and 2 in the Southern part.

Geothermal resources



Parameter	U/M	Western Plain
Type of reservoir		sandstone
Area	km^2	2,500
Depth	km	0.8÷2.1
Drilled wells	(total)	88
Active wells		37
Well head temp.	°C	50÷85
Temperature gradient	°C/100	3.8÷5.0
TDS	g/l	2÷7
GWR	Nm^3/m^3	0.5÷2.5
Type of production		Artesian+Pumping
Flow rate	l/s	4÷40
Operations		37
Annual savings	toe	18,500
Total installed power (with existing wells)	MW_t	210
Exploitable reserves (for 20 years)	MW/day	4,700
Main uses:		
space heating	dwellings	2,460
sanitary hot water	dwellings	2,200
greenhouses	ha	34
industrial uses	operations	7
health bathing	operations	8

❑ Most of geothermal deposits are located in the western part of Romania, in the eastern part of the Pannonian Basin.

❑ Pannonian geothermal aquifer is multi-layered and cover an area of approximately 2,500 km^2, along the western border of Romania, from Satu Mare in the north to Timisoara and Jimbolia in the south. From geological point of view the geothermal waters in the western part of the country are located in the following structures:

- porous - permeable sandy rocks (sandstones) at the basement of Upper Pannonian (800m to 2,100m depth)
- fractured / fissured rocks (limestone and dolomite) of Mesozoic age at a depth of deposits between 1,000m and 3,500m,

❑ The water temperatures are between 40 and 120 °C, the heat source being the upper mantle (asthenosphere) and/or magma chambers located at different depths in the Earth's crust.

❑ The geothermal gradient is 45-55 °C/km. The mineralisation of the geothermal waters is 4÷5 g/l (sodium-bicarbonate-chloride type) and most of the waters show carbonate scaling, prevented by downhole chemical inhibition. The wells are produced mainly artesian, but also with downhole pumps.

The geothermal area Mures-Crisul Negru (Arad county)

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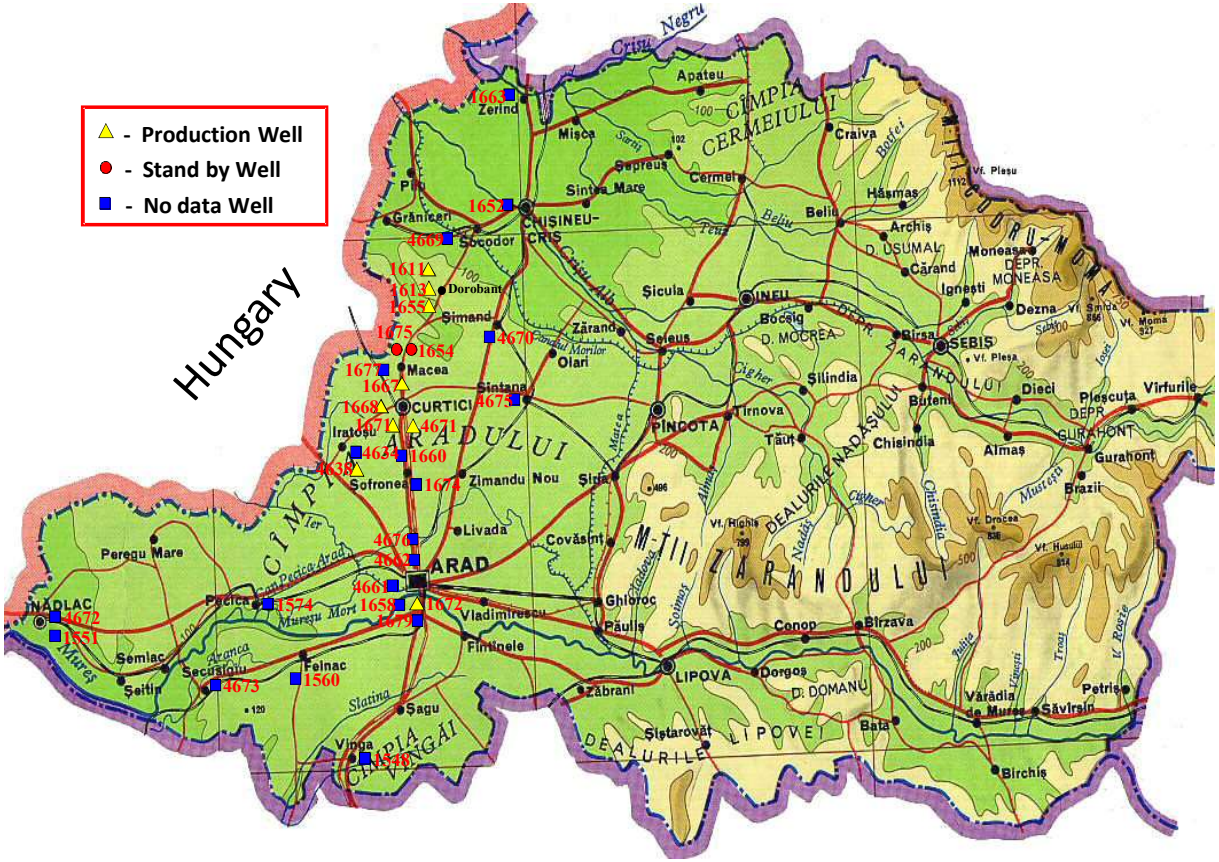
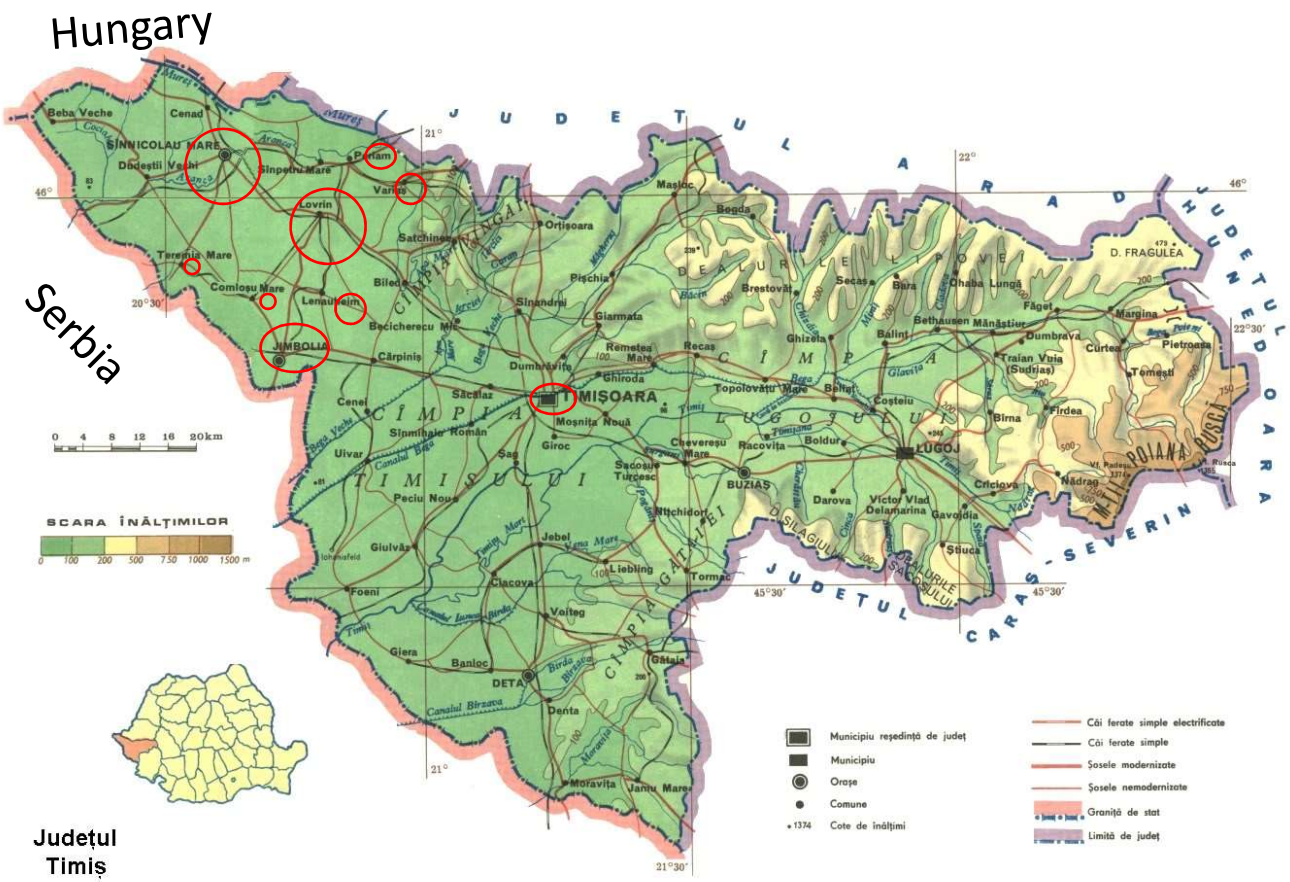


The area Mures – Crisul Negru is located in the south of Crisana Plain and north of Banat Plain. It belongs to the lower Pannonian. The aquifer is multilayered type, consisting of alternating layers of semi permeable and porous and permeable formations of the basement of Upper Pannonian.

The water temperatures are between 50 and max. 70 °C without carbonate scaling tendency. The mineralisation of the geothermal waters is 1.8÷2.5 g/l (sodium-bicarbonate-chloride type). The combustible gases, mainly methane, are separated from the water.

Geothermal waters can be unrestricted discharged into rivers, lakes, canals, being included in water without toxic lethal action.

The geothermal area Timis (Banatul de Vest)



Județul Timiș

Production wells location

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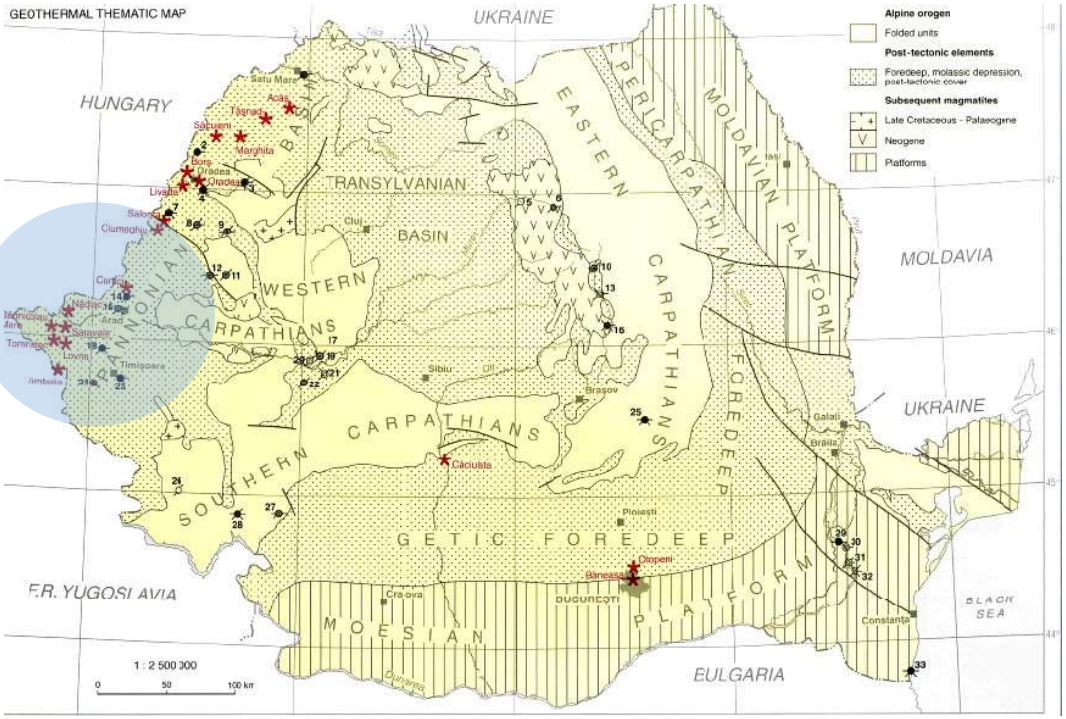
Geological research conducted during 1976 - 1999 by drilling, testing and production of the geothermal wells at the basement of the Upper Pannonian revealed the Banatul de Vest geothermal system which is currently the largest geothermal aquifer in the country. The extent of the system is an area of approximately 2100 km². Is delimited conventionally south, west and north of the state border (extending far in Hungary and Serbia).

The water temperatures are between 80 and 100 °C (at 1700 -1900m depth). The mineralisation of the geothermal waters is 2.5÷4.5 g/l (sodium-bicarbonate-chloride type) and the flow rate up to 30 l/s.

Current utilization



Legend of the Table – type of utilisation

H = Space heating & district heating (other than heat pumps)
B = Bathing and swimming (including balneology)
A = agricultural drying (grain, fruit, vegetables)
I = industrial process heat
G = Greenhouse and soil heating
F = Fish and animal farming

Locality	Type	Maximum Utilisation			Capacity		Annual Utilisation	
		Flow Rate	Temperature (°C)			Ave. Flow	Energy	Capacity
		(l/s)	Inlet	Outlet	(MWt)	(l/s)	(TJ/yr)	Factor
Satu Mare	HB	12	65	30	1.8	7	32.3	0.56
Carei	BI	5	45	30	0.3	3	5.9	0.62
Acas	GB	15	65	30	2.2	8	36.9	0.53
Tasnad	HBG	10	70	25	1.9	7	41.5	0.69
Beltiug	B	6	75	30	1.1	4	23.7	0.68
Sacuieni	HBGFI	8	80	25	5.1	12	87.1	0.54
Marghita	HB	6	65	25	2.0	10	52.8	0.83
Boghis	BH	12	45	25	1.0	10	26.4	0.83
Mihai Bravu	GF	6	65	25	1.0	0	0	0.00
Bors	G	25	115	40	7.8	0	0	0.00
	IHGBF	85	83	30	18.8	65	415.0	0.70
Livada	BF	10	88	35	2.2	5	35.0	0.50
Felix	BH	140	45	25	11.7	115	216.0	0.58
Madaras	BH	5	46	25	0.4	3	8.3	0.65
Ciumeghiu	G	12	92	35	2.9	0	0	0.00
Cighid	HBG	10	72	25	2.0	6	37.2	0.59
Beius	HB	44	83	30	9.7	15	104.9	0.34
Macea	*HGB*	*15*	*65*	*25*	*2.5*	*8*	*42.2*	*0.53*
Curtici	*HGB*	*22*	*63*	*25*	*3.5*	*14*	*70.2*	*0.63*
Dorobanti	*GB*	*18*	*60*	*25*	*2.6*	*9*	*41.5*	*0.50*
Sofronea	*HB*	*6*	*42*	*25*	*0.4*	*3*	*6.7*	*0.53*
Iratos	*IB*	*5*	*40*	*20*	*0.4*	*3*	*7.9*	*0.63*
Arad	*B*	*12*	*40*	*25*	*0.8*	*7*	*13.8*	*0.54*
Nadlac	*IHB*	*10*	*78*	*30*	*2.0*	*8*	*50.6*	*0.80*
Sannicolau	*IHBG*	*50*	*78*	*30*	*10.0*	*35*	*221.6*	*0.70*
Saravale	*HB*	*8*	*75*	*25*	*1.7*	*5*	*33.0*	*0.61*
Tomnatic	*GB*	*45*	*80*	*30*	*9.4*	*22*	*145.1*	*0.49*
Lovrin	*HGB*	*40*	*81*	*30*	*8.5*	*30*	*132.0*	*0.49*
Periam	*HB*	*10*	*70*	*25*	*1.9*	*6*	*35.6*	*0.59*
Jimbolia	*IHGB*	*50*	*82*	*30*	*10.9*	*35*	*240.1*	*0.70*
Teremia	*IHB*	*15*	*85*	*30*	*3.5*	*6*	*43.5*	*0.39*
Comlosu	*HB*	*10*	*81*	*25*	*2.3*	*6*	*44.3*	*0.61*
Grabat	*IB*	*6*	*80*	*30*	*1.3*	*3*	*19.8*	*0.48*
Beregsau	*IB*	*6*	*75*	*25*	*1.3*	*3*	*19.8*	*0.48*
Timisoara	*HB*	*15*	*45*	*25*	*1.3*	*10*	*26.4*	*0.64*
Herculane	*B*	*75*	*52*	*25*	*8.5*	*50*	*148.0*	*0.55*
TOTAL		889			156.6	659	2840.8	